Field Evaluation
AQMesh v5.1 - Gas

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

- From 04/11/2020 to 06/18/2020[1], three **AQMesh v5.1** (**hereinafter AQMesh**) multi-sensor pods were deployed at the South Coast AQMD stationary ambient monitoring site in Rubidoux and were run side-by-side with Federal Equivalent Method (FEM) and Federal Reference Method (FRM) instruments measuring the same pollutants

- AQMesh (*3 units tested*):
  - Sensors: CO – Electrochemical (Alphasense, non-FEM)
    O_3 – Electrochemical (Alphasense, non-FEM)
    NO – Electrochemical (Alphasense, non-FEM)
    NO_2 – Electrochemical (Alphasense, non-FEM)
    SO_2 – Electrochemical (Alphasense, non-FEM)
  - PM Sensors – Optical Particle Counter (AQMesh OPC v3.0, non-FEM)
  - Each unit measures: **CO (ppb), O_3 (ppb), NO, NO_2 and NO_x (ppb), SO_2 (ppb)**, $PM_{1.0}$, $PM_{2.5}$ and PM_{10} ($\mu g/m^3$), T (°C), RH (%)
  - Unit cost: ~$7,800 as tested (includes 5 gas pods + PM sensor, equipped with a heated inlet), price includes daily data downloads
  - Time resolution: 5-min
  - Units IDs: 0381, 0383, 0385

- South Coast AQMD Reference instruments:
  - CO instrument (FRM); cost: ~$7,000
    - Time resolution; 1-min
  - O_3 instrument (FEM); cost: ~$7,000
    - Time resolution; 1-min
  - NO_X instrument (FRM NO_2); cost: ~$11,000
    - Time resolution: 1-min
  - Met station (T, RH, P, WS, WD); cost: ~$5,000
    - Time resolution: 1-min

[1]Note: sensor data were not available between 5/5/2020 and 5/14/2020 due to preventive maintenance activities at the monitoring site

AQMesh: Rebasing & Data Scaling

Rebasing

- Prior to this AQ-SPEC field evaluation, the AQMesh pods were required by the manufacturer to go through a stabilization process called "rebasing". It is configured to rebase when it comes from the factory to allow the sensors to evaluate the environmental conditions they are operating and adjust accordingly
- AQMesh needs to be notified to trigger the rebasing process, which takes 48 to 72 hours to complete. Gas data were not available during the rebasing period but will be backfilled to the time when rebasing initiated

Data Scaling

- AQMesh provides prescaled and scaled values for all gas pollutants. Scaled values were calculated using AQMesh's proprietary algorithms
- AQMesh's scaled data were used in AQ-SPEC's data analysis for all gas pollutants

AQMesh: Limit of Confidence (LOC)

- All gas measurement data collected during this field evaluation, that were below AQMesh's limit of confidence (LOC) values (see AQMesh table below), were removed and not included in this analysis

Technical specification | Gas algorithm V5.1, PM algorithm V3.0h*

Gases

Sensor	Type	Units	Range[#1]	LOD	LOC[#2]	Precision[#3]	Accuracy[#4]
NO	Electrochemical	ppb or µg/m³	0-20,000 ppb	<1 ppb	<5 ppb	>0.9	1 ppb
NO2	Electrochemical	ppb or µg/m³	0-20,000 ppb	<1 ppb	<5 ppb	>0.85	4 ppb
NOx	Electrochemical	ppb or µg/m³	0-40,000 ppb	<2 ppb	<10 ppb	>0.9	4 ppb
O3	Electrochemical	ppb or µg/m³	0-20,000 ppb	<1 ppb	<5 ppb	>0.9	5 ppb
CO	Electrochemical	ppb or µg/m³	0-1,000,000 ppb	<50 ppb	<50 ppb	>0.8	20 ppb
SO2	Electrochemical	ppb or µg/m³	0-100,000 ppb	<5 ppb	<10 ppb	>0.7	20 ppb
H2S	Electrochemical	ppb or µg/m³	0-100,000 ppb	<1 ppb	<5 ppb	>0.7	1 ppb
CO2	NDIR	ppm or mg/m³	0-5,000 ppm	<1 ppm	<1 ppm	>0.9	30 ppm

#1 From sensor manufacturer's specification. This data was derived from independent lab tests. Standard test conditions are 20°C and 80% RH and in the absence of interfering gases. Tested range is -30°C to +30°C.

#2 Readings provided below this level, however due to interferences the level of uncertainty is greater than at higher levels of the target pollutant.

#3 Correlation co-efficient derived from extensive global co-location comparison testing against certified reference.

#4 Best "out of the box" accuracy without any local scaling/calibration against reference.

Source: https://www.aqmesh.com/product/technical-specification/

Carbon Monoxide (CO) in AQMesh

Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery for CO from Unit 0381, Unit 0383 and Unit 0385 was ~ 94%, 95% and 96%, respectively

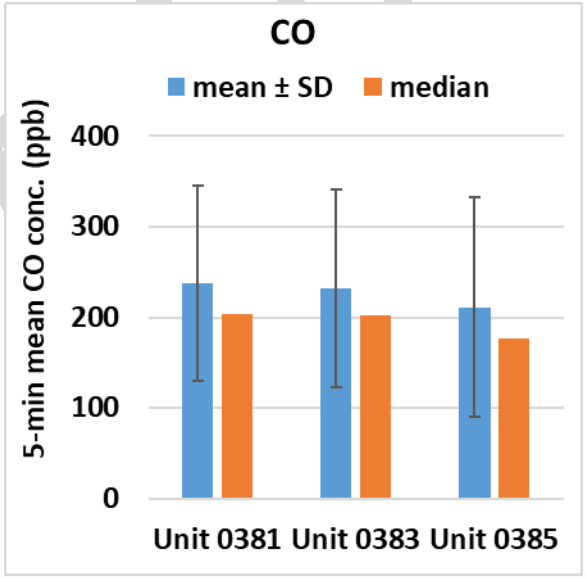
AQMesh; Intra-model variability

- Absolute intra-model variability was ~ 13.8 ppb for the CO measurements

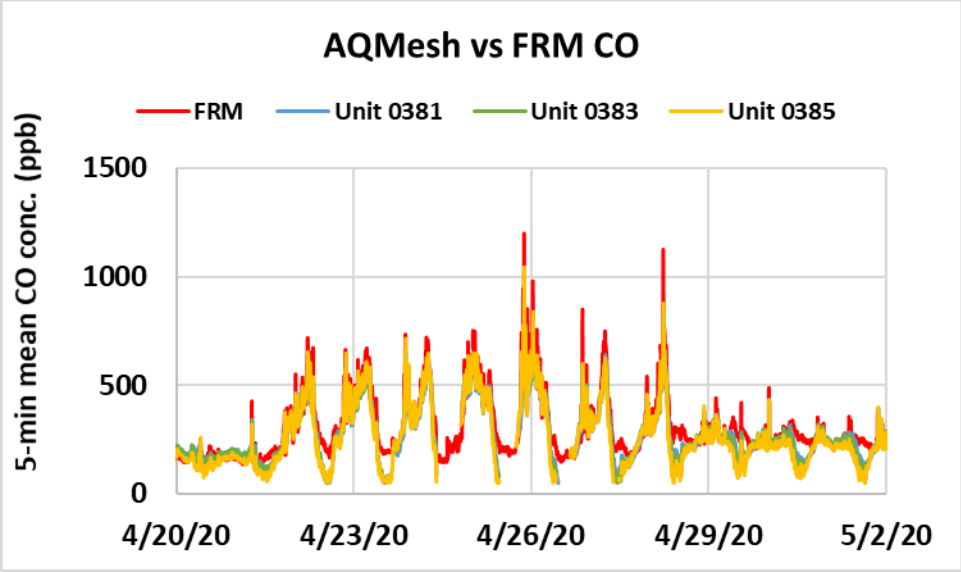
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 6.1% for the CO measurements

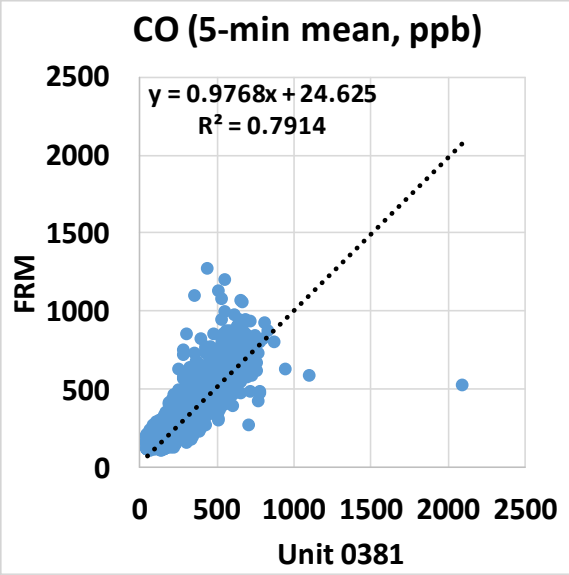
(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

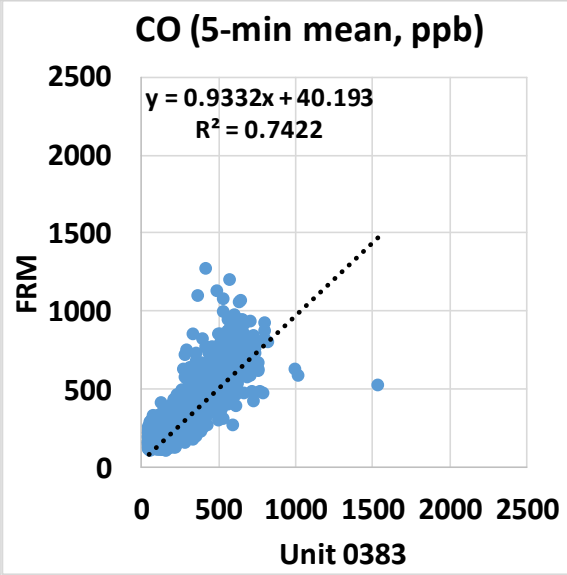


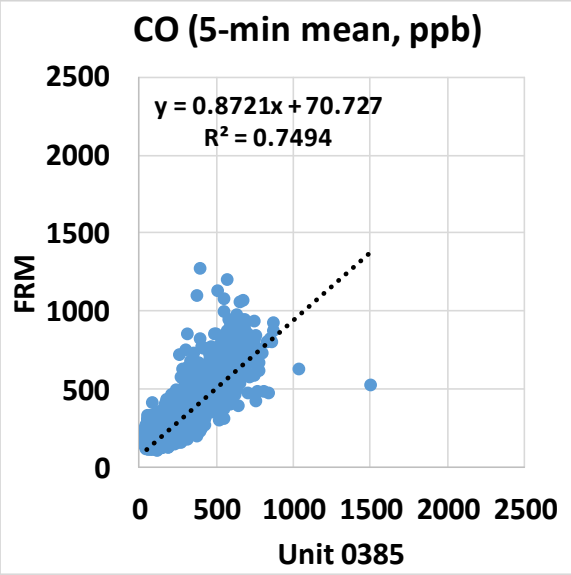
AQMesh vs FRM (CO; 5-min mean)



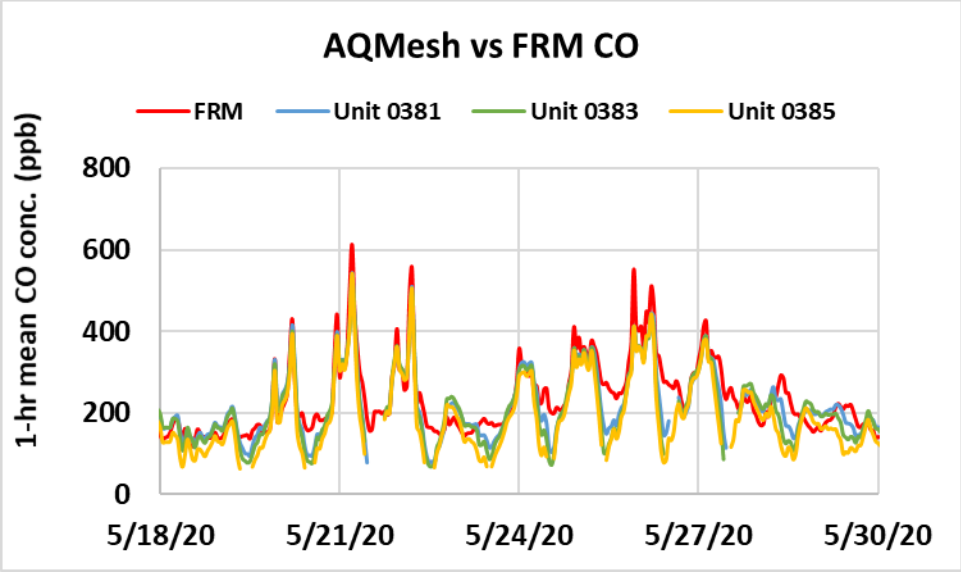
- The AQMesh sensors showed strong correlations with the corresponding FRM CO data (R^2 ~ 0.76)
- Overall, the AQMesh sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The AQMesh sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument



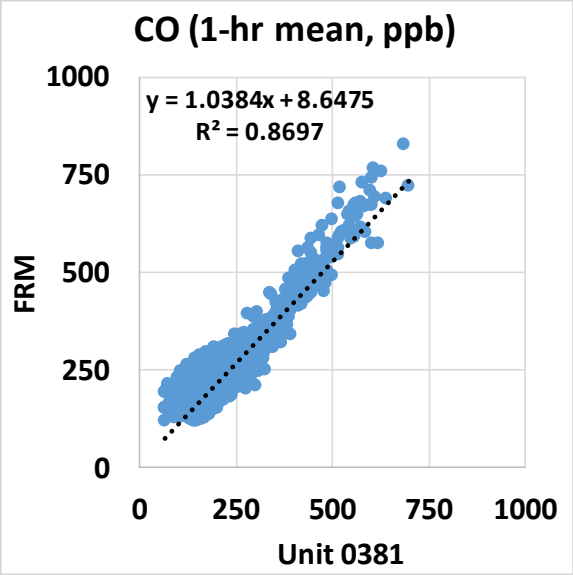


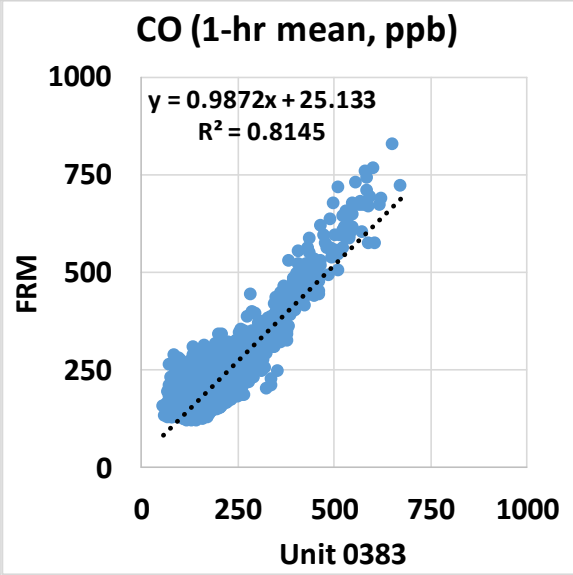


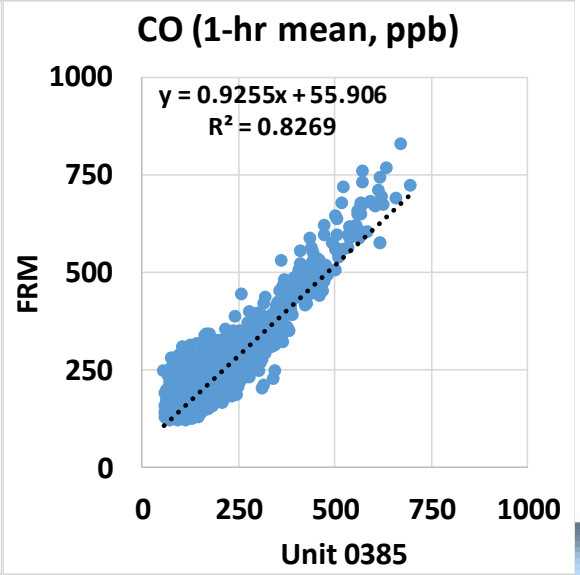
AQMesh vs FRM (CO; 1-hr mean)



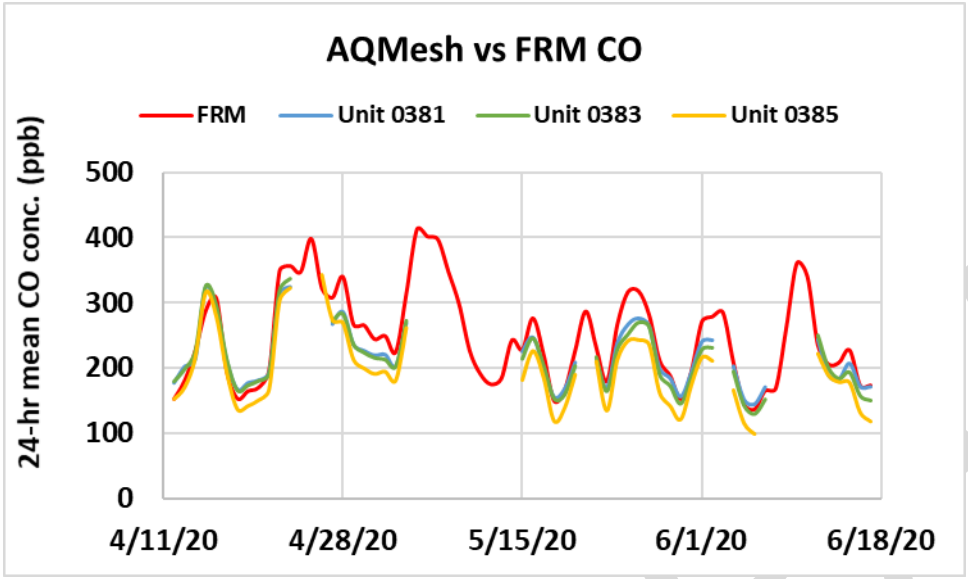
- The AQMesh sensors showed strong correlations with the corresponding FRM CO data (R^2 ~ 0.84)
- Overall, the AQMesh sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The AQMesh sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument



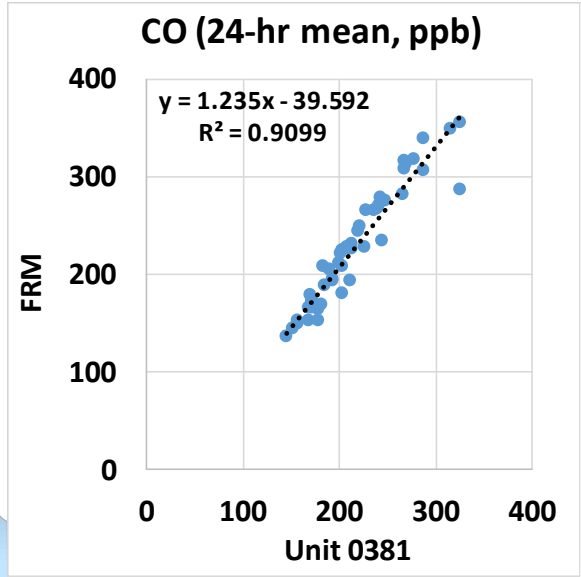


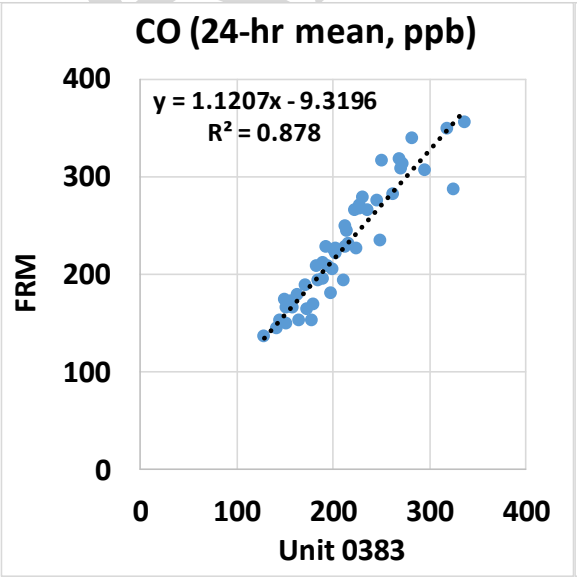


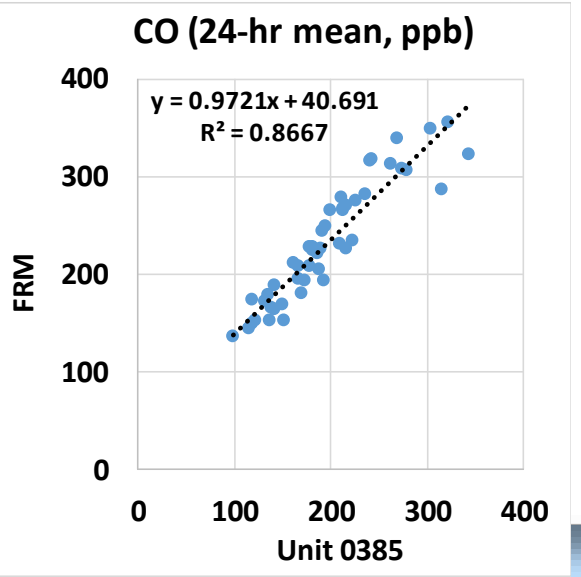
AQMesh vs FRM (CO; 24-hr mean)



- The AQMesh sensors showed strong to very strong correlations with the corresponding FRM CO data ($0.87 < R^2 < 0.91$)
- Overall, the AQMesh sensors underestimated the CO concentrations as measured by the FRM CO instrument
- The AQMesh sensors seemed to track the diurnal CO variations as recorded by the FRM CO instrument







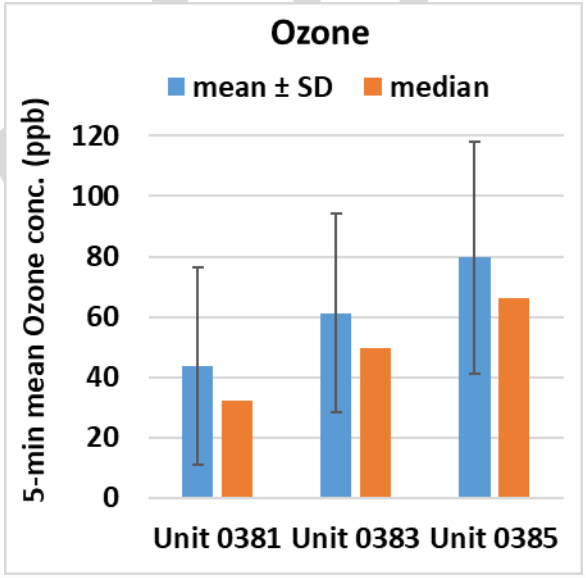
Ozone (O_3) in AQMesh

Data validation & recovery

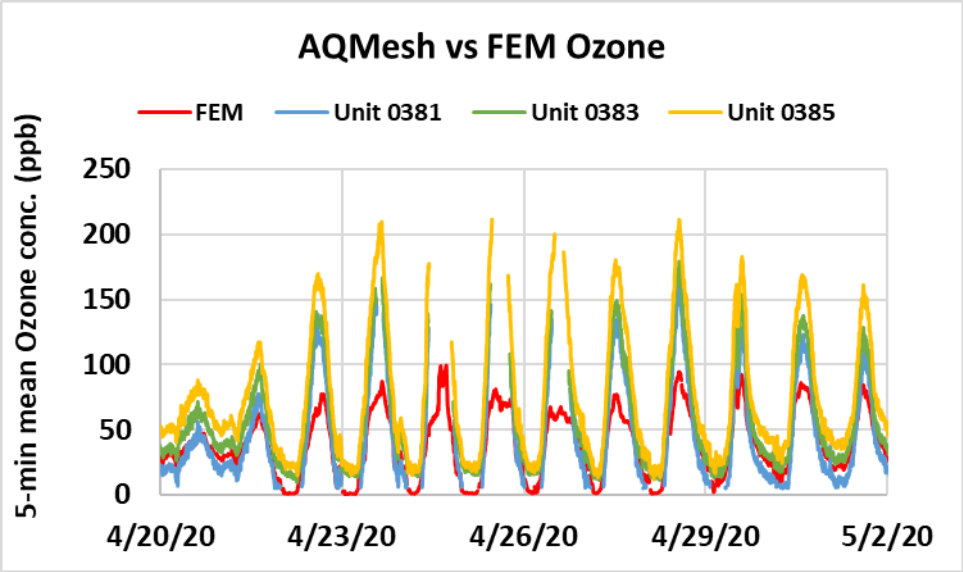
- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery for ozone from Unit 0381, Unit 0383 and Unit 0385 was ~ 82%, 95% and 96%, respectively

AQMesh; Intra-model variability

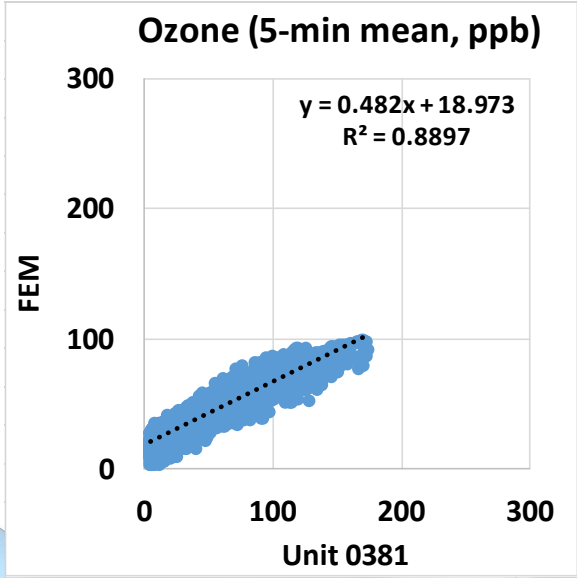
- Absolute intra-model variability was ~ 18 ppb for the ozone measurements (calculated as the standard deviation of the three sensor means)
- Relative intra-model variability was ~ 29.2% for the ozone measurements (calculated as the absolute intra-model variability relative to the mean of the three sensor means)

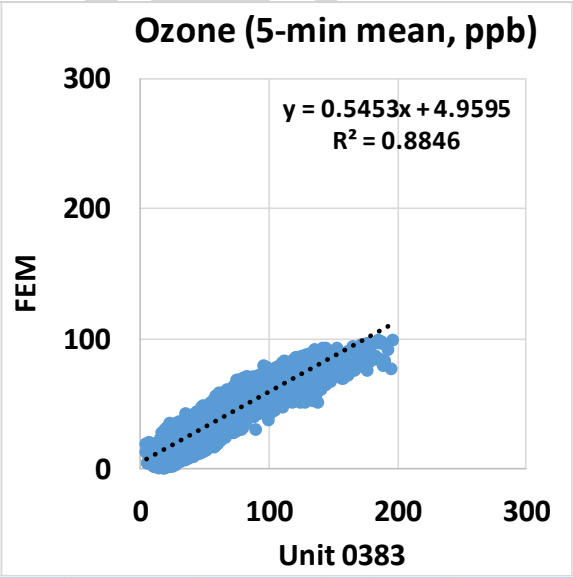


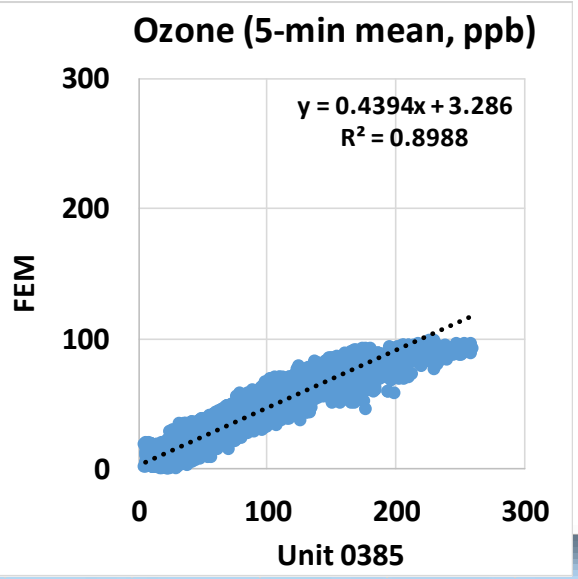
AQMesh vs FEM (Ozone; 5-min mean)



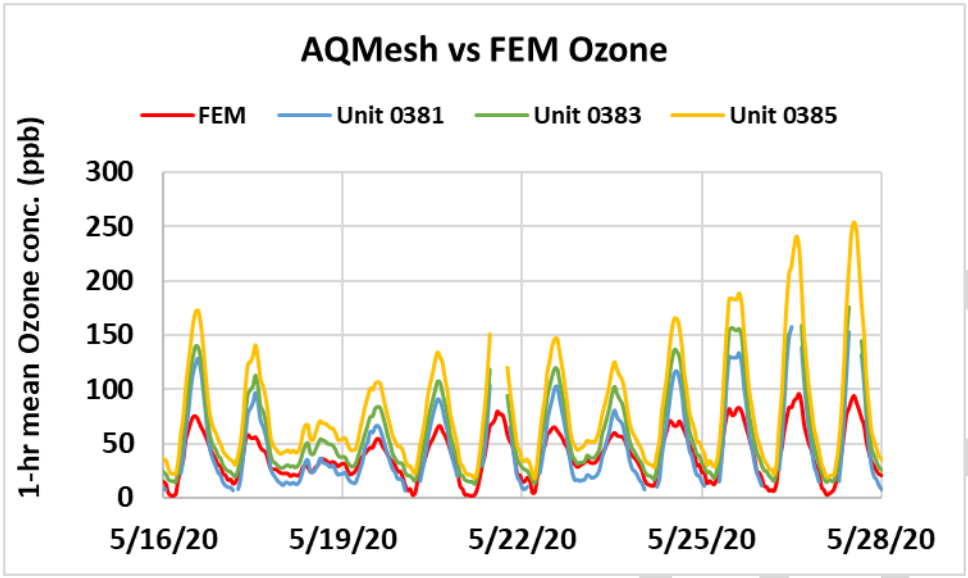
- The AQMesh sensors showed strong correlations with the corresponding FEM ozone data (R^2 ~ 0.89)
- Overall, the AQMesh sensors overestimated the ozone concentrations as measured by the FEM ozone instrument
- The AQMesh sensors seemed to track the diurnal ozone variations as recorded by the FEM ozone instrument



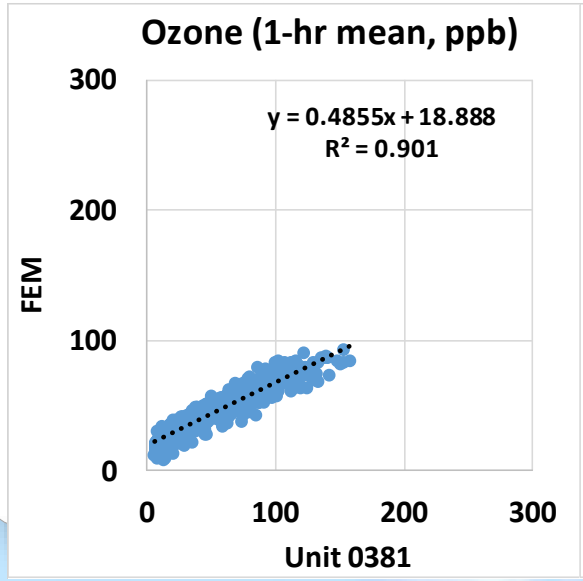


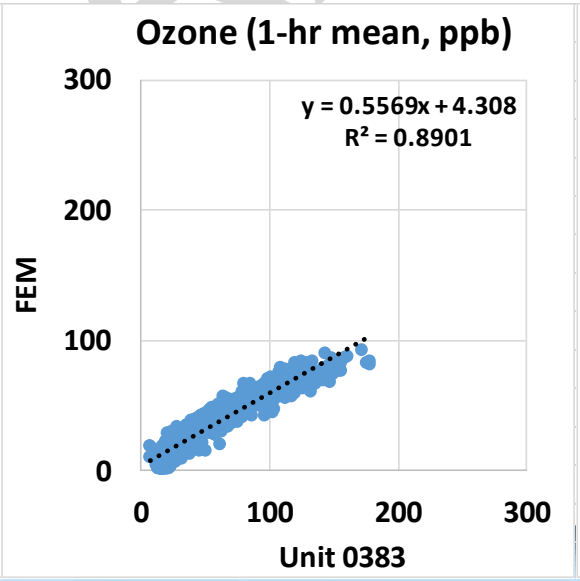


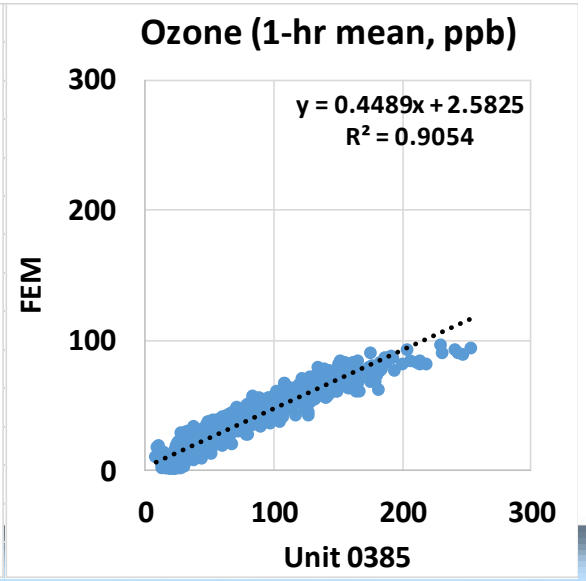
AQMesh vs FEM (Ozone; 1-hr mean)



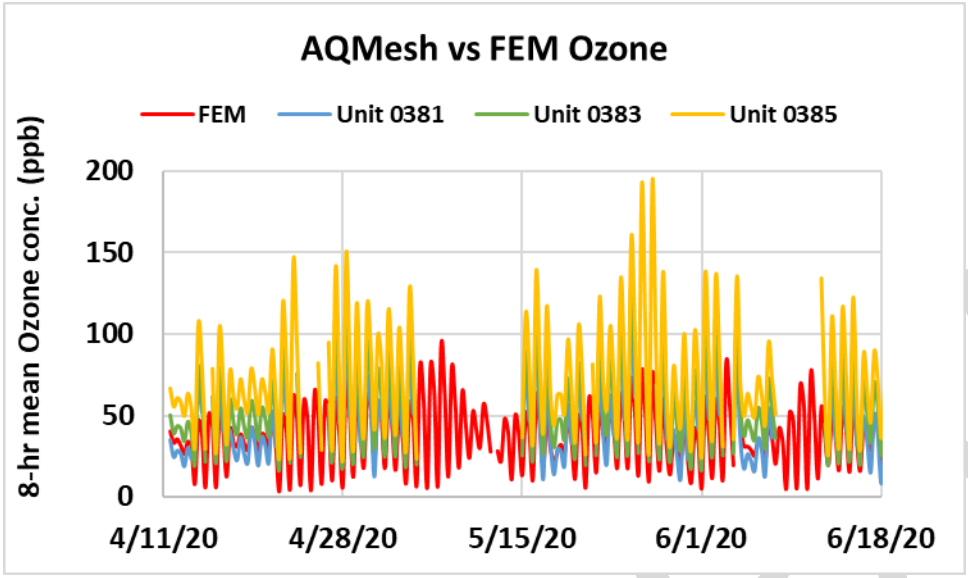
- The AQMesh sensors showed strong to very strong correlations with the corresponding FEM ozone data ($0.89 < R^2 < 0.91$)
- Overall, the AQMesh sensors overestimated the ozone concentrations as measured by the FEM ozone instrument
- The AQMesh sensors seemed to track the diurnal ozone variations as recorded by the FEM ozone instrument



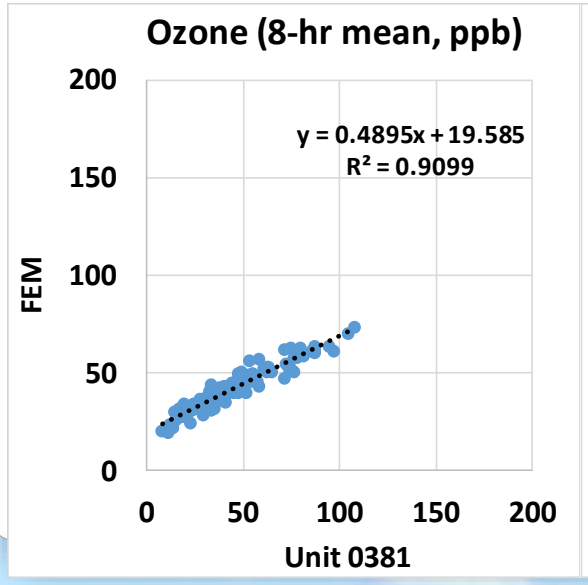


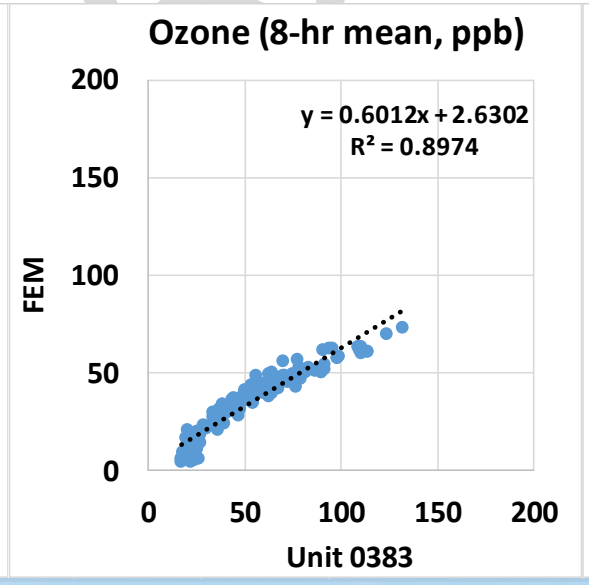


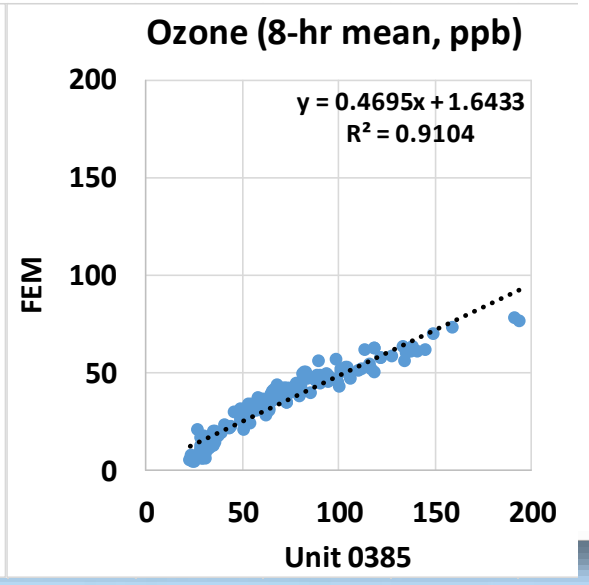
AQMesh vs FEM (Ozone; 8-hr mean)



- The AQMesh sensors showed strong to very strong correlations with the corresponding FEM ozone data ($0.89 < R^2 < 0.92$)
- Overall, the AQMesh sensors overestimated the ozone concentrations as measured by the FEM ozone instrument
- The AQMesh sensors seemed to track the diurnal ozone variations as recorded by the FEM ozone instrument







Nitric Oxide (NO) in AQMesh

Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery for NO from Unit 0381, Unit 0383 and Unit 0385 was ~ 84%, 87% and 73%, respectively

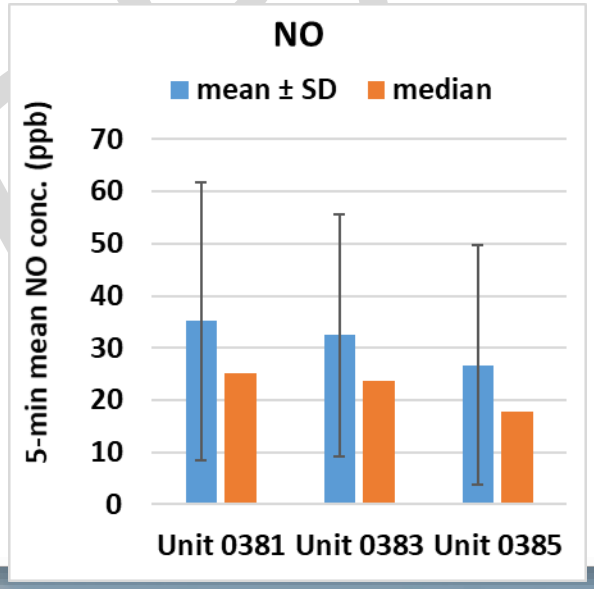
AQMesh; Intra-model variability

- Absolute intra-model variability was ~ 4.3 ppb for the NO measurements

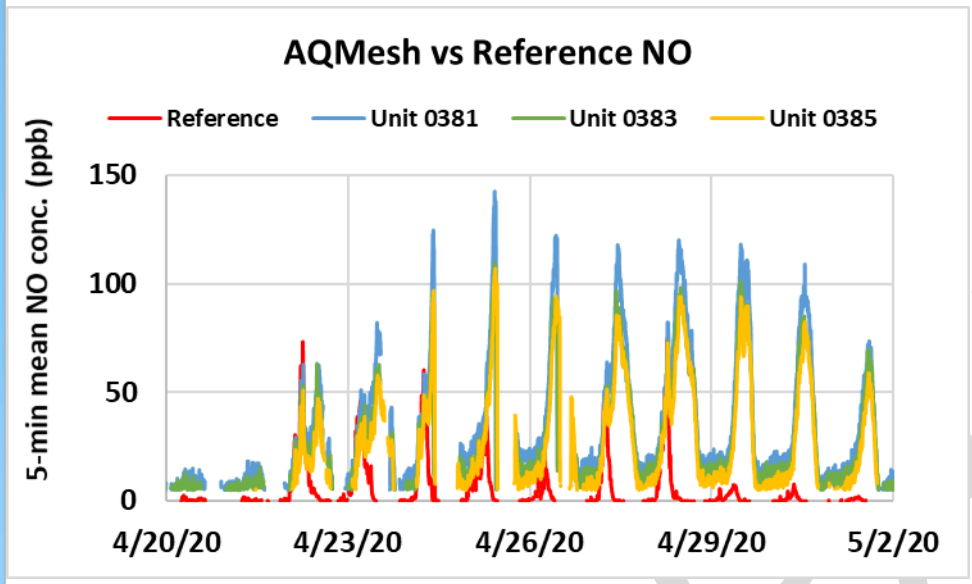
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 13.6% for the NO measurements

(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

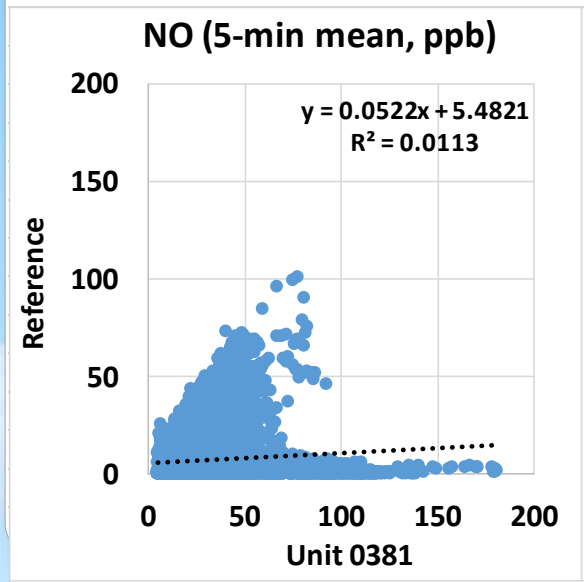


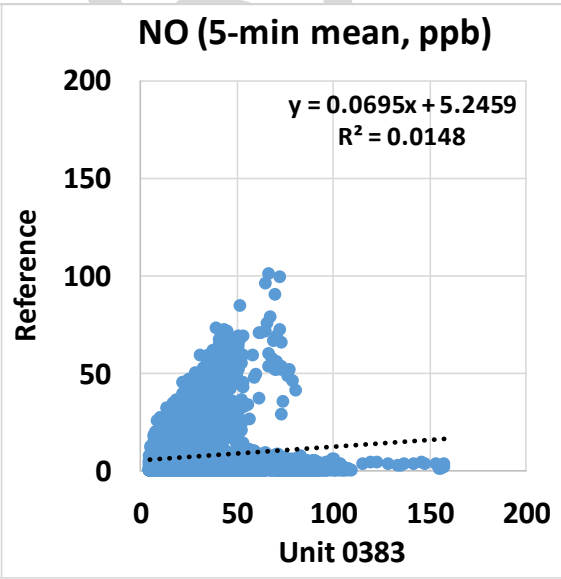
AQMesh vs Reference (NO; 5-min mean)

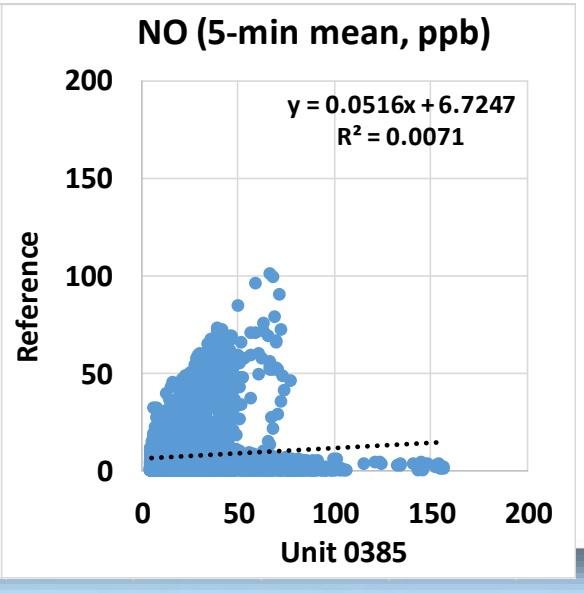


- The AQMesh sensors did not correlate with the corresponding reference NO data (R^2 ~ 0.01)
- Overall, the AQMesh sensors overestimated the NO concentrations as measured by the reference instrument
- The AQMesh sensors did not seem to track the diurnal NO variations as recorded by the reference instrument

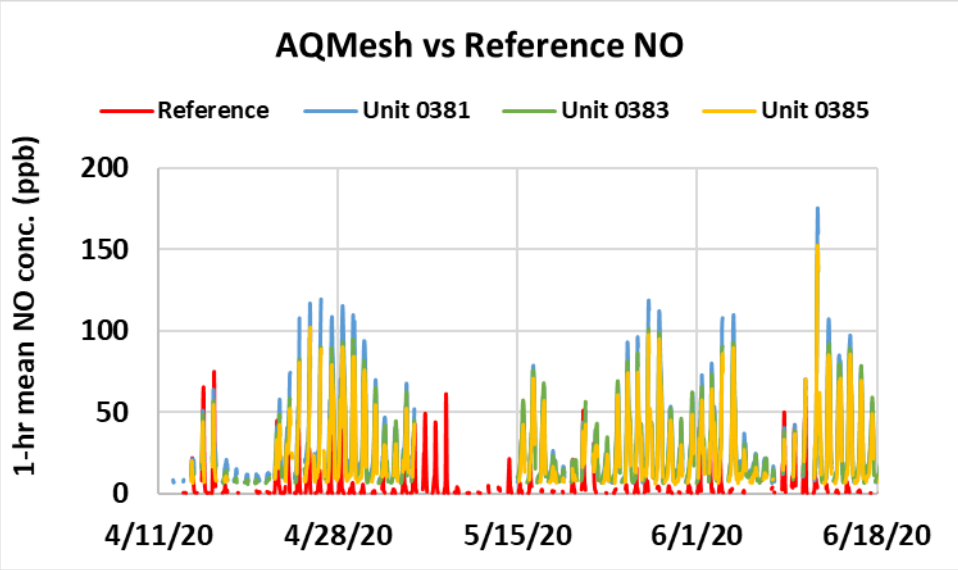
Note: Reference NO data were removed if the values were negative. 24-hr data were not shown due to the lack of data.





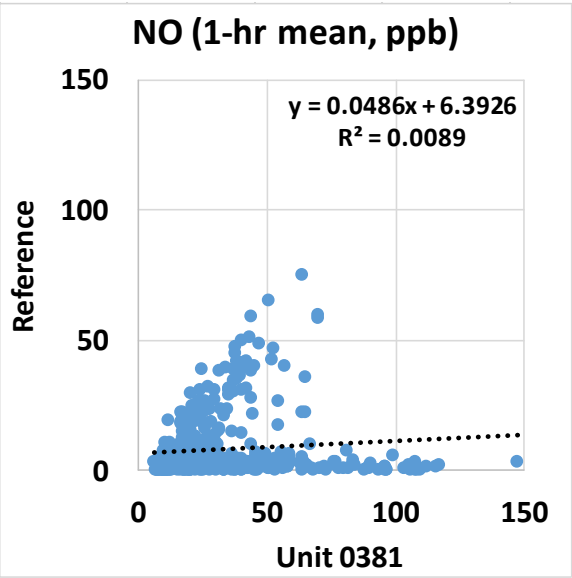


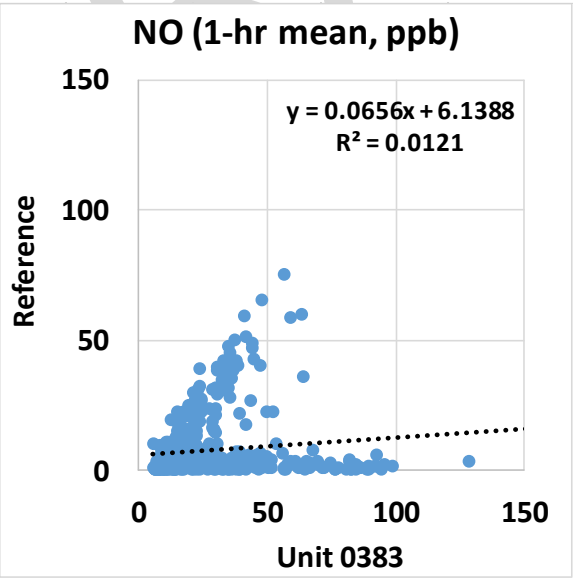
AQMesh vs Reference (NO; 1-hr mean)

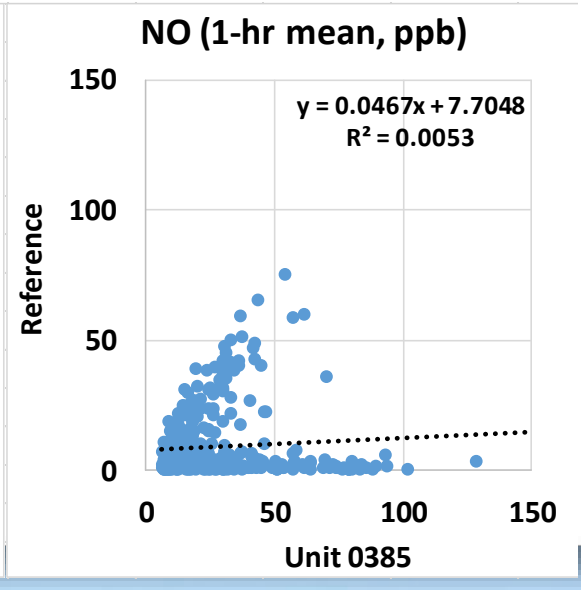


- The AQMesh sensors did not correlate with the corresponding Reference NO data (R^2 ~ 0.01)
- Overall, the AQMesh sensors overestimated the NO concentrations as measured by the reference instrument
- The AQMesh sensors did not seem to track the diurnal NO variations as recorded by the reference instrument

Note: Reference NO data were removed if the values were negative. 24-hr data were not shown due to the lack of data.







Nitrogen Dioxide (NO_2) in AQMesh

Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values and invalid data-points were eliminated from the data-set)
- Data recovery for NO_2 from Unit 0381, Unit 0383 and Unit 0385 was ~ 94%, 94% and 96%, respectively

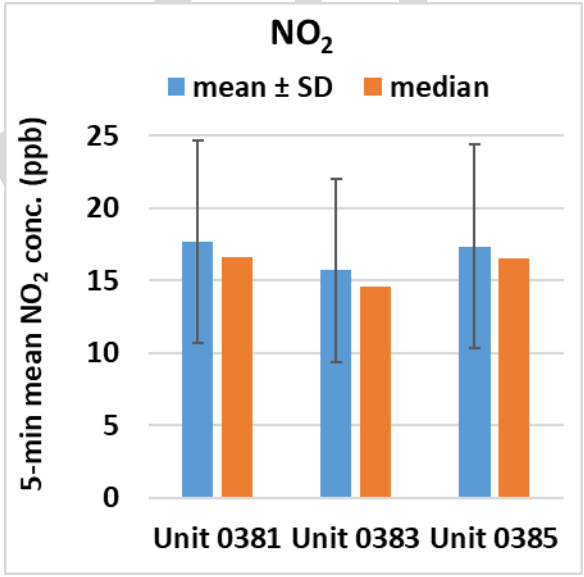
AQMesh; Intra-model variability

- Absolute intra-model variability was ~ 1.1 ppb for the NO_2 measurements

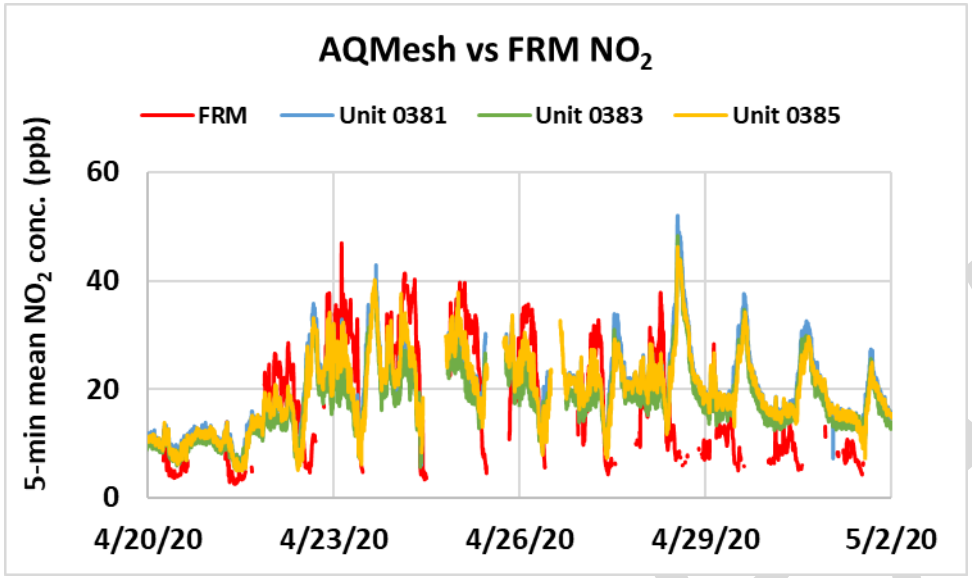
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 6.3% for the NO_2 measurements

(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

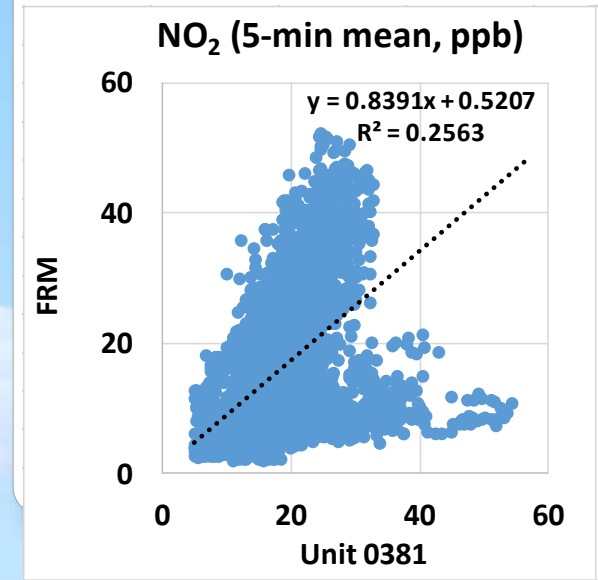


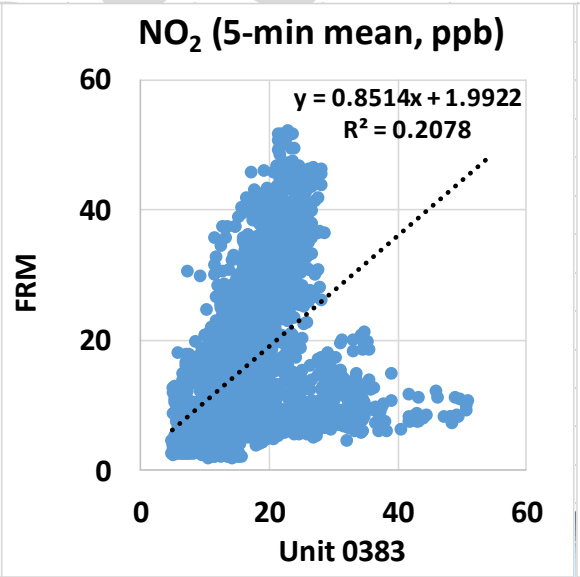
AQMesh vs FRM (NO_2; 5-min mean)

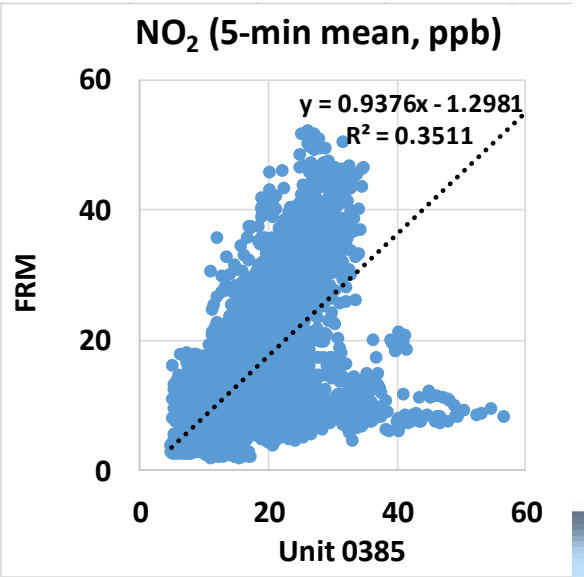


- The AQMesh sensors showed very weak to weak correlations with the corresponding FRM NO_2 data ($0.20 < R^2 < 0.36$)
- Overall, the AQMesh sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The AQMesh sensors did not seem to track the diurnal NO_2 variations as recorded by the FRM instrument

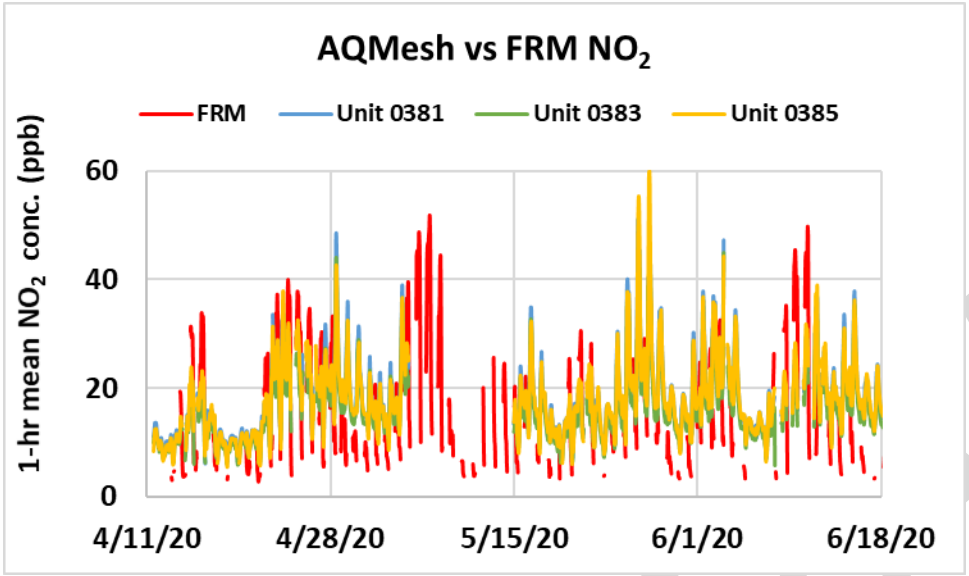
Note: FRM NO_2 (calculated as the difference between NO_x and NO) data were removed if the corresponding NO values were negative. 24-hr data were not shown due to the lack of data.





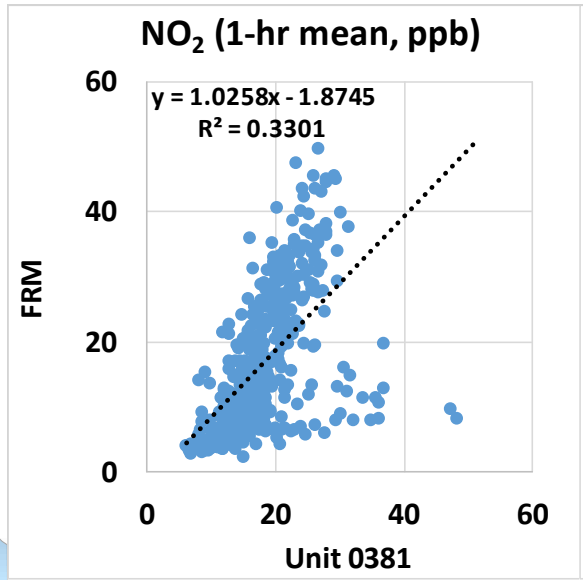


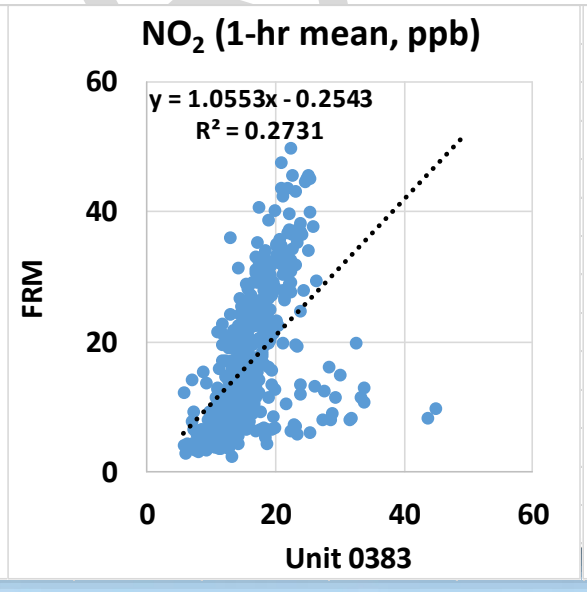
AQMesh vs FRM (NO_2; 1-hr mean)

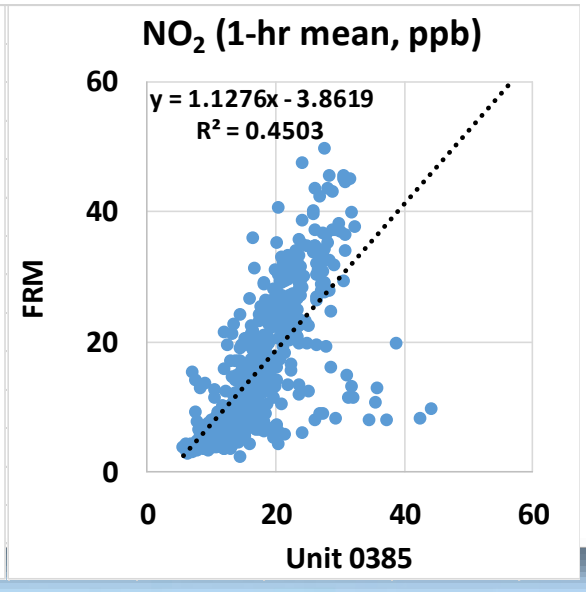


- The AQMesh sensors showed very weak to weak correlations with the corresponding FRM NO_2 data ($0.27 < R^2 < 0.46$)
- Overall, the AQMesh sensors overestimated the NO_2 concentrations as measured by the FRM instrument
- The AQMesh sensors did not seem to track the diurnal NO_2 variations as recorded by the FRM instrument

Note: FRM NO_2 (calculated as the difference between NO_x and NO) data were removed if the corresponding NO values were negative. 24-hr data were not shown due to the lack of data.







Nitrogen Oxides (NO_x) in AQMesh

Data validation & recovery

- Basic QA/QC procedures were used to validate the collected data (i.e., obvious outliers, negative values, and invalid data-points were eliminated from the data-set)
- Data recovery for NO_x from Unit 0381, Unit 0383 and Unit 0385 was ~ 94%, 94% and 96%, respectively
- AQMesh NO_x is calculated as the sum of NO and NO_2. NO_x measurements were considered for this data analysis if 1) the NO_x values were higher than AQMesh's LOC and 2) the corresponding NO and NO_2 were both above AQMesh's LOC

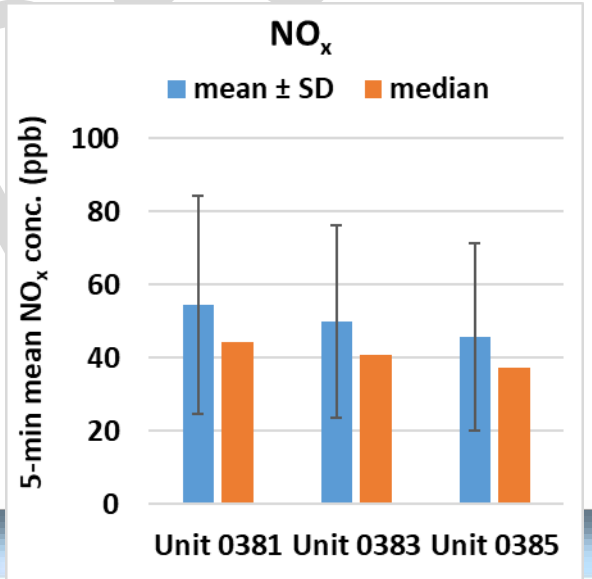
AQMesh; Intra-model variability

- Absolute intra-model variability was ~ 4.4 ppb for the NO_x measurements

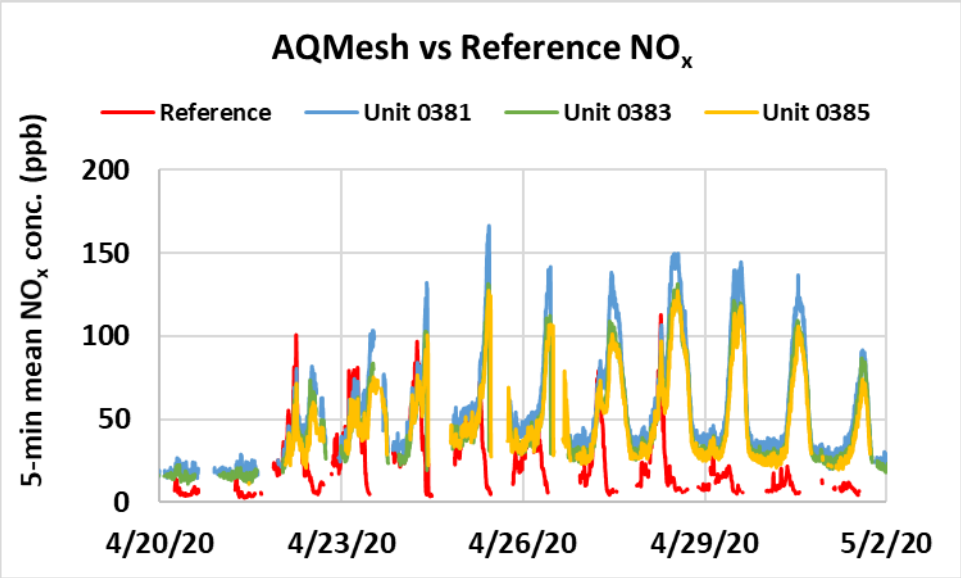
(calculated as the standard deviation of the three sensor means)

- Relative intra-model variability was ~ 8.8% for the NO_x measurements

(calculated as the absolute intra-model variability relative to the mean of the three sensor means)

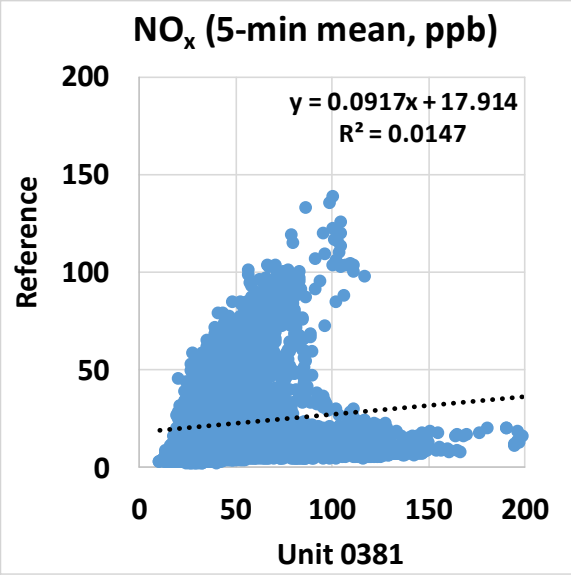


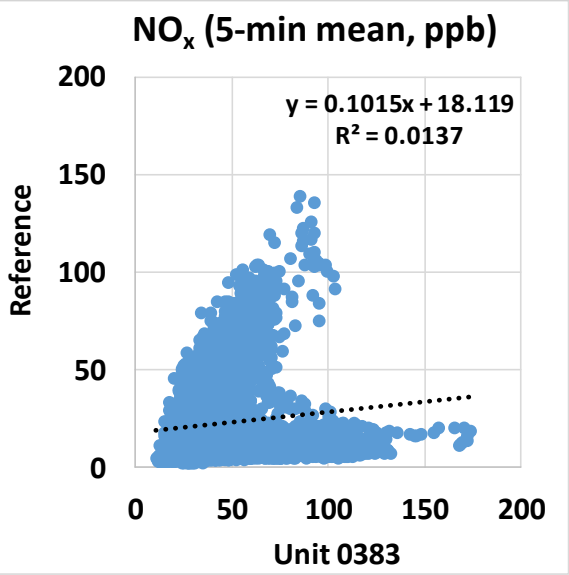
AQMesh vs Reference (NO_x; 5-min mean)

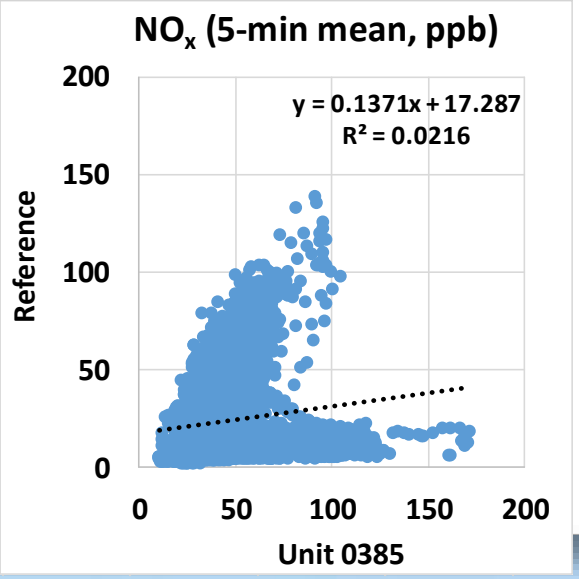


- The AQMesh sensors did not correlate with the corresponding reference NO_x data (R^2 ~ 0.017)
- Overall, the AQMesh sensors overestimated the NO_x concentrations as measured by the reference instrument
- The AQMesh sensors did not seem to track the diurnal NO_x variations as recorded by the reference instrument

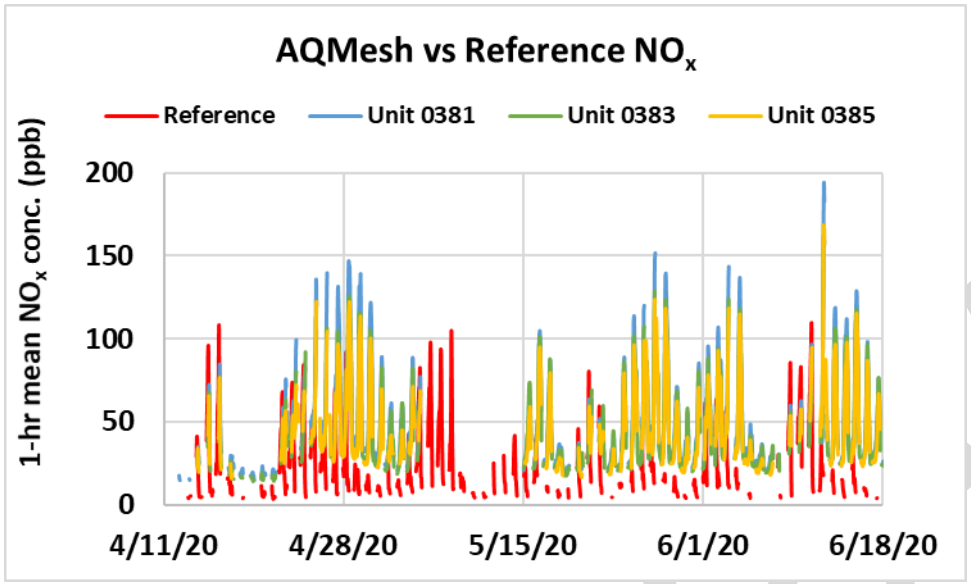
Note: Reference NO_x data were removed if the corresponding NO values were negative. 24-hr data were not shown due to the lack of data.





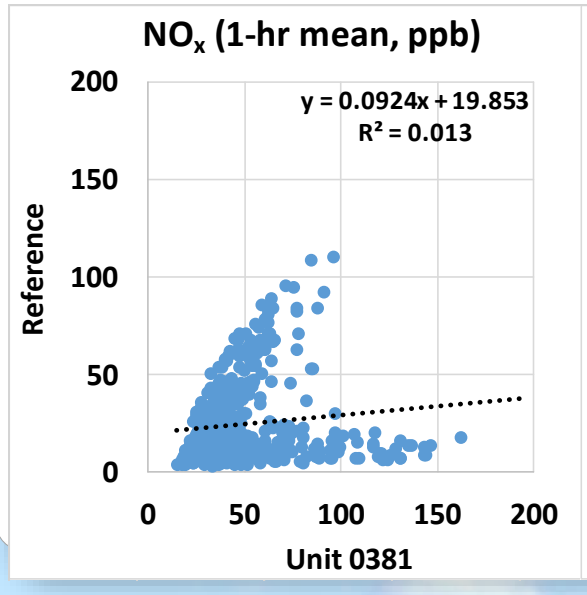


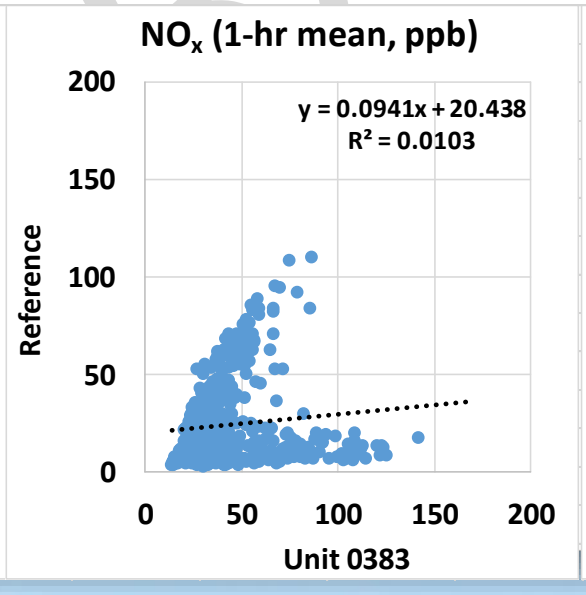
AQMesh vs Reference (NO_x; 1-hr mean)

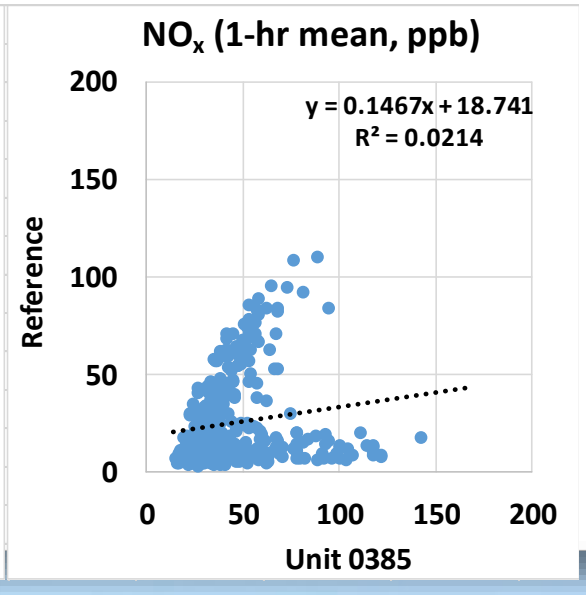


- The AQMesh sensors did not correlate with the corresponding reference NO_x data (R^2 ~ 0.01)
- Overall, the AQMesh sensors overestimated the NO_x concentrations as measured by the reference instrument
- The AQMesh sensors did not seem to track the diurnal NO_x variations as recorded by the reference instrument

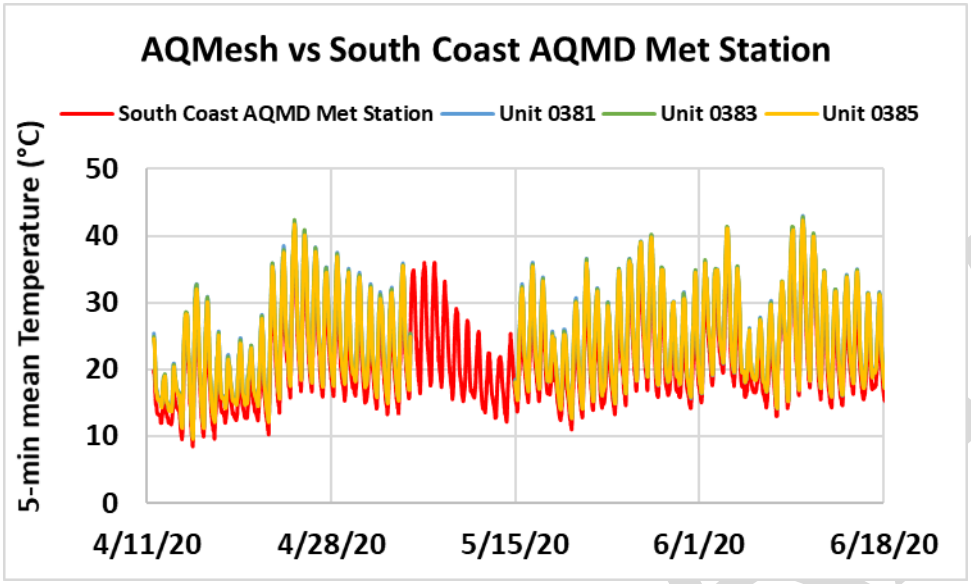
Note: Reference NO_x data were removed if the corresponding NO values were negative. 24-hr data were not shown due to the lack of data.



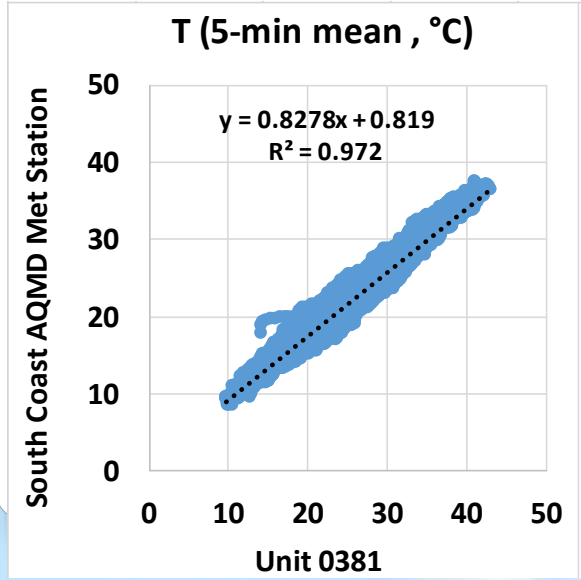


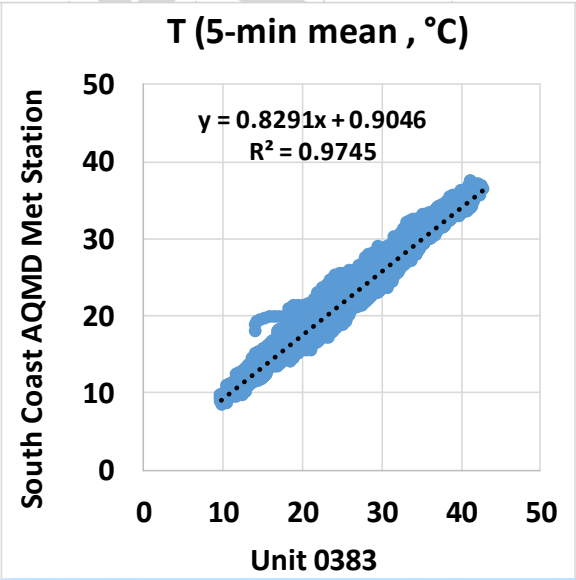


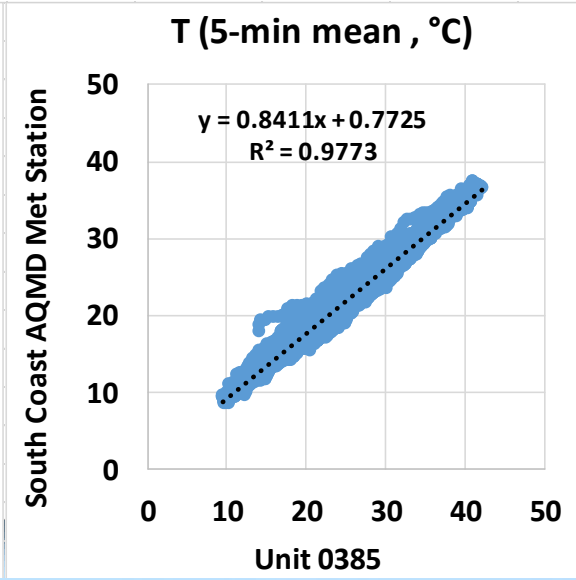
AQMesh vs South Coast AQMD Met Station (Temp; 5-min mean)



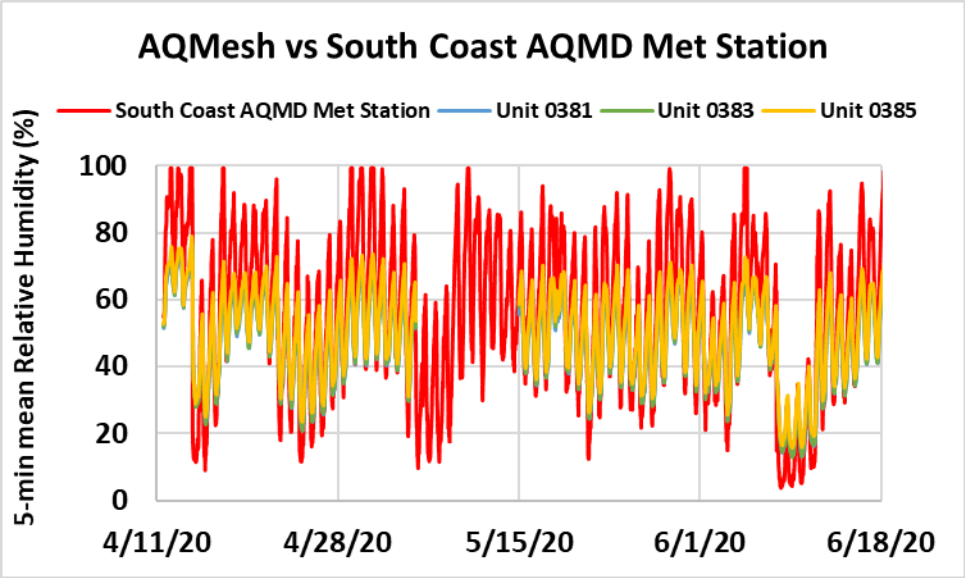
- The AQMesh sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.97)
- Overall, the AQMesh sensors overestimated the temperature measurement as recorded by South Coast AQMD Met Station
- The AQMesh sensors seemed to track the diurnal temperature variations as recorded by South Coast AQMD Met Station



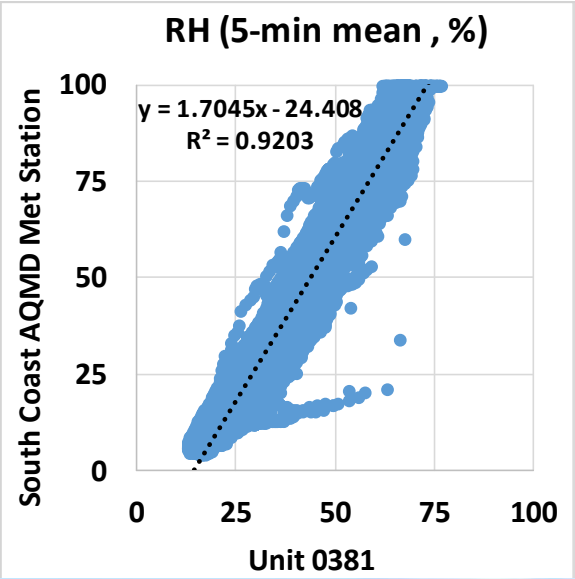


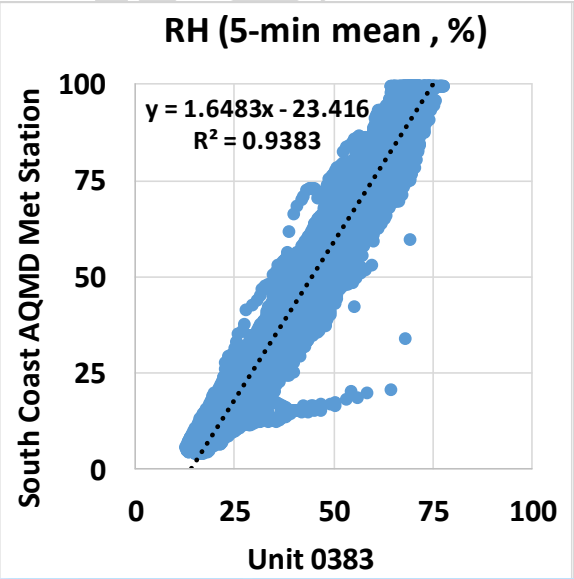


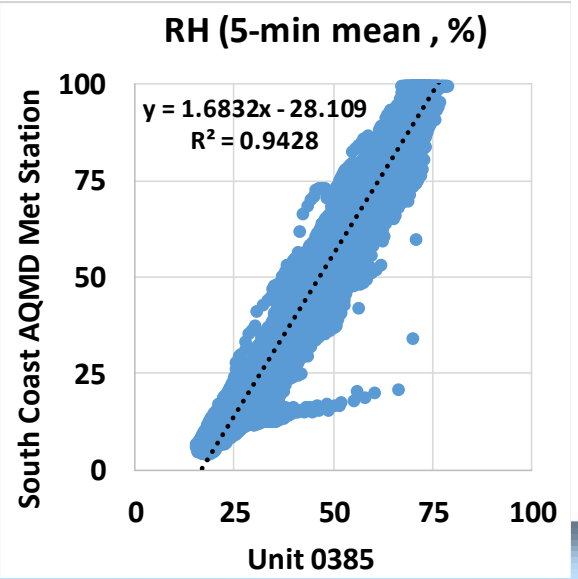
AQMesh vs South Coast AQMD Met Station (RH; 5-min mean)



- The AQMesh sensors showed very strong correlations with the corresponding South Coast AQMD Met Station data (R^2 ~ 0.93)
- Overall, the AQMesh sensors underestimated the RH measurement as recorded by South Coast AQMD Met Station
- The AQMesh sensors seemed to track the diurnal RH variations as recorded by South Coast AQMD Met Station







Discussion

- The average data recovery of three **AQMesh** sensors for CO, ozone, NO, NO_2 and NO_x was 95%, 91%, 81%, 95% and 95%, respectively.
- The absolute intra-model variability for CO, ozone, NO, NO_2 and NO_x was ~ 13.8, 18, 4.3, 1.1 and 4.4 ppb, respectively.
- During the entire field deployment testing period:
  - CO sensors showed strong correlations with the FRM instrument (R^2 ~ 0.76, 5-min mean) and underestimated the corresponding FRM data
  - Ozone sensors showed strong correlations with the FEM instrument (R^2 ~ 0.89, 5-min mean) and overestimated the corresponding FEM data
  - Nitric Oxide (NO) sensors did not correlate with the reference instrument (R^2 ~ 0.01, 5-min mean) and overestimated the corresponding reference data
  - NO_2 sensors showed very weak to weak correlations with the FRM instrument ($0.20 < R^2 < 0.36$, 5-min mean) and overestimated the corresponding FRM data
  - NO_x sensors did not correlate with the reference instrument (R^2 ~ 0.017, 5-min mean) and overestimated the corresponding reference data
  - SO_2 evaluation was not included in this report since the majority of the AQMesh SO_2 values were below AQMesh's limit of confidence (LOC) of 10 ppb as specified in the technical specification from AQMesh
  - Temperature and relative humidity sensors showed very strong correlations with the South Coast AQMD Met Station data (T: R^2 ~ 0.97 and RH: R^2 ~ 0.93) and overestimated the T data and underestimated the RH data as recorded by the South Coast AQMD Met Station
- No sensor calibration was performed by AQ-SPEC prior to the beginning of this field testing.
- Laboratory chamber testing is necessary to fully evaluate the performance of these sensors under controlled T and RH conditions, and known target and interferent pollutants concentrations.
- These results are still preliminary